1992

Levee/Floodwall Freeboard Design For An Urban Flood Control Project

Daniel B. Pridal
U.S. Army Engineer District

Edward F. Sing
U.S. Army Engineer District

Published in Hydraulic Engineering: Saving a Threatened Resource—In Search of Solutions: Proceedings of the Hydraulic Engineering sessions at Water Forum '92.
Baltimore, Maryland, August 2–6, 1992. Published by American Society of Civil Engineers.

Levee/Floodwall Freeboard Design For An Urban Flood Control Project

Daniel B. Pridal and Edward F. Sing, M. ASCE[1]

Abstract

A methodology for the design of levee/floodwall freeboard using evolving guidelines based on the concept of superiority is presented. A case study illustrating the application of the freeboard design guidelines to the Truckee Meadows Project is shown. The Truckee Meadows Project provides a 100 year level of flood protection through the Reno-Sparks, Nevada metropolitan area along an approximate ten mile reach of the Truckee River. Major features of the project include levees, floodwalls, channel modifications, bridge replacement or reconstruction, a detention basin, and drainage improvements. The project is presently in the Preconstruction, Engineering and Design (PED) Phase within the Sacramento District of the U.S. Army Corps of Engineers.

Introduction

Design guidance on establishing levee/floodwall freeboard through heavily urbanized areas is evolving within the Corps of Engineers. A generic design of freeboard assigns a uniform amount of freeboard throughout the project reach without considering specific project features. Typical freeboard values cited within EM-1110-2-1601 (1991) are often considered to be 2 feet in concrete channels and 3 feet for earth levees. Evolving freeboard design guidance focuses the need to consider not only flow conveyance but also minimization of levee freeboard toward decreasing project construction costs, accommodating flows greater than the design event, and identifying potential levee/floodwall overtopping locations at least hazardous locations. Levee superiority results in a variation of freeboard throughout the project and is proposed as a means of hydraulically addressing levee freeboard design issues. Design of project freeboard is intended to prevent catastrophic failure of project features.

The case study presented on the Truckee Meadows project illustrates several important

---

[1]Hydraulic Engineers, U.S. Army Engineer District - Sacramento, 1325 J Street, Sacramento, California 95814-2922

considerations in freeboard design. The Truckee River is bounded on both sides by residential and commercial development along the project reach. Existing local modifications which affect channel conveyance include low levees, floodwalls, boulder-type diversion dams and irrigation takeoff structures. Within a typical channel cross section, a river berm separates the river channel from the existing low levees and floodwalls within which mature riparian vegetation thrives and a recreational path has been provided. The proposed flood control project includes raising of the existing levees and floodwalls with minimal disturbance to the existing vegetation and recreational features.

Freeboard Design Guidance

Evolving freeboard design guidance based on levee superiority with initial overtopping in the least hazardous locations is presented by Huffman (1990) and in ETL 1110-2-299 (1986). The freeboard of a channel is typically designated as the vertical distance from the computed design water surface elevation to the top of the channel levee or floodwall. The concept of superiority with respect to freeboard refers to varying the amount of freeboard by reach according to specific project design considerations. Freeboard is incorporated within project design to insure against overtopping of project features due to uncertainties in water surface profile computations and project maintenance. Freeboard insures that the desired degree of protection for the project is not reduced due to these uncertainties. Examples of factors which contribute to computation uncertainty are errors due to model simplification of flow phenomena, dynamic effects, and project operation and maintenance. Other factors which can be reasonably quantified and which influence the computed design water surface elevation should be included in profile computations and not assumed to be included in the project freeboard. Examples of factors which can be quantified include changes in conveyance due to variations in channel shape and roughness, and evaluation of energy losses at locations of rapid change in flow area caused by abrupt contractions and expansions. For a full discussion of the separation of factors which are included in project freeboard and in design profile computations, refer to Huffman (1990).

Project freeboard is often roughly estimated in early study phases and refined as the study progresses. The freeboard design methodology presented here is intended to be performed following a "final design" level of water surface profile computations for the project. A condensed summary of the freeboard design method, as presented by Huffman (1990) and adapted for the Truckee Meadows project, contains five steps and is briefly summarized as follows:

1. Determine the water surface profile for the design event using appropriate computation methods through the project reach.
2. Compute the water surface profile through the project reach using a maximum loss estimate and the design flow rate.
3. Select the location(s) of initial overtopping of project structures for a flow greater than the design event. The computed water surface elevation determined in step 2 is used to set the minimum levee grade at the initial overtopping locations.
4. Using the normal estimate for losses, determine the flow rate which results in a water surface elevation similar to that determined in step 3 at initial overtopping points. Compute a water surface profile for the reach using the high flow rate and normal loss estimates.
5. Determine the levee superiority throughout the reach. As well as other factors,

levee grade should consider the variation in water surface profile slope for the flood hydrograph, superiority at critical locations, and a gradually increasing length of levee overtopping as flood stages rise.

Truckee Meadows Case Study

The following paragraphs describe the design steps and the manner in which the freeboard design guidelines were applied to the Truckee Meadows Project. Other projects will require consideration of additional features and concerns not included in the Truckee Meadows project. Ideally, freeboard design should be performed utilizing an unsteady flow model. HEC-2, a steady, gradually varied flow water surface profile computation model, was used as the design model for the Truckee Meadows application due to the long duration of the flood hydrograph and project time and cost considerations. The performed freeboard design analysis was based on evaluation with respect to Truckee River flow only. An interior drainage analysis should be conducted following the freeboard design to determine the possibility of induced flooding. Interior drainage considerations may result in the need to adjust levee superiority.

Step 1.- Hydraulic studies of the Truckee River and tributaries within the project study area were conducted to determine design water surface elevations and required project features to meet project objectives. The current version of the HEC-2 computer program "Water Surface Profiles" was used to compute water surface profiles for the project design event using peak flow rates which varied from 18500 to 20300 cfs through the project reach. The Manning resistance coefficient was used to assess boundary roughness within the cross section. The Truckee Meadows flood control project study area upstream boundary is the Booth Street bridge near the western city limit of Reno at river mile (RM) 53. The project extends downstream at a moderately steep slope of approximately 0.005 ft/ft to the vicinity of RM 47.4 where the river slope decreases to 0.001 ft/ft as the river flows through the Truckee Meadows to the downstream project limit at Vista at RM 43. The freeboard design for the project reach downstream of U.S. Highway 395, at RM 50.6, was performed separately from the reach upstream. The highway is elevated above the flood plain and travels perpendicular to the direction of flow. Flows which overtop upstream project structures are contained by U.S. 395 and returned to the Truckee River for floods which exceed the design event, including the SPF. The freeboard design described in steps 2-5 applies to the reach on the Truckee River from RM 43 - 50.6, only (between Vista and U.S. Hwy 395).

Step 2.- For the Truckee River, the maximum loss profile computation was determined by applying a factor of 1.25 to the normal loss n value used in the HEC-2 model for computation of the design profile. The maximum loss computed water surface elevation exceeded the normal loss elevation by approximately 1.5 feet at RM 47.2. Due to the high velocity nature of flood flows through the project reach upstream of this location and the existence of waves that could exceed the 1.5 foot height, a minimum levee grade of 2.0 feet was selected for the downstream most initial overtopping location at RM 47.2.

Step 3.- Selection of overtopping locations within the reach analyzed was based on historical overflow locations, least hazardous overtopping areas due to overbank usage and levee configuration, the slope of the flow profile, the highly urbanized nature of the lands adjacent to the project features, and other constraints. The design process determined that multiple overtopping locations were required to insure that catastrophic failure of the project features does not occur and that any levee/floodwall overtopping is distributed over the project reach in a manner that would minimize flood inducement behind these features. After an iterative process of freeboard design steps 2-4, three locations of overtopping, or areas of reduced levee superiority above the design profile, were identified as:

1. Both banks over project levee, RM 47.2 - The overbank area behind the left project levee at this location is light industrial and behind the right project levee is the University of Nevada, Reno, farms.

2. Both banks over project levee, RM 48.6 - The overbank area behind the left project levee at this location is light industrial and behind the right project levee is undeveloped.

3. Right bank over project floodwall, RM 49.7 - The overbank area behind the right bank floodwall is the parking lot for a casino. The casino building is elevated above the parking lot. The left overbank is an area that would be a breakout location under preproject conditions, but is presently developed as a water treatment plant and was therefore excluded from consideration as an overtopping location.

Step 4.- The flow rate which corresponds to an increase of 2.0 feet in the computed water surface elevation selected in step 3 was determined to be 23,500 cfs. The 23,500 cfs freeboard design flood (FDF) peak discharge corresponds to a return interval of 160 year for the Truckee River and is a ratio of 1.27 times the design flow. The reasonableness of the magnitude of the FDF was assessed with respect to the design peak flow of 18,500 cfs and the SPF peak flow of 39,500 cfs and was determined to be acceptable. The elevation of the FDF profile was used to set the levee grade at the initial overtopping locations.

Step 5.- For the Truckee Meadows project, levee grade was determined using the concept of levee superiority. Superiority was added above the FDF profile to insure that initial overtopping of project levees occurred at the desired location and sequence with respect to the multiple overtopping locations. The discharge from each of the overtopping locations was computed using the split flow option within HEC-2 by modeling flow over the overtopping section as weir flow. A sensitivity analysis was performed to assess the effect of the design head and the weir discharge coefficient with respect to the HEC-2 split flow computed discharge at the overtopping location. Selection of the weir flow coefficient considered the depth of flow over the weir, the approach angle of flow, and debris expected during a major flood event. Conservative values, with respect to the flow remaining in the river downstream of the overtopping location, were assumed to assure that actual discharge during a flood event equaled or exceeded the computed discharge.

Through an iterative hydraulic analysis, the length and elevation of each initial overtopping location and the superiority of each reach was determined. With respect to computation and construction accuracy limits, an increment of 0.5 feet in levee superiority between reaches was assumed reasonable. For the purposes of the analysis, flow capacity within each reach was computed at the top of levee. Increasing superiority was added to levee height in the upstream direction. The overtopping length determined for each location of reduced superiority was based on the required amount of discharge from the river such that the remaining flow in the channel downstream of the overtopping section was at or below capacity of the reach, based on the superiority of the reach. Length was also based on the amount of discharge required to allow all three overtopping sections to function collectively for flows greater than the design event. The intent of the freeboard design was to assure that, as the flow rate exceeds the design event, levee overtopping and flow occurs at the desired location. The lenght of the overtopping sections, or reach of reduced levee superiority, was determined as 1000 feet for the left and right bank levees at RM 47.2, 800 feet left bank and 1200 feet right bank for the levees at RM 48.6, and 450 feet for the right bank floodwall at RM 49.7. The iterative analysis determined the elevation of the initial overtopping points at RM 47.2 and RM 49.7 should be set at the same minimum grade elevation (i.e., at the FDF profile), and the RM 48.6 overtopping point 0.5 feet above the FDF profile. A graphic illustration of the final freeboard design is shown in figure 1.

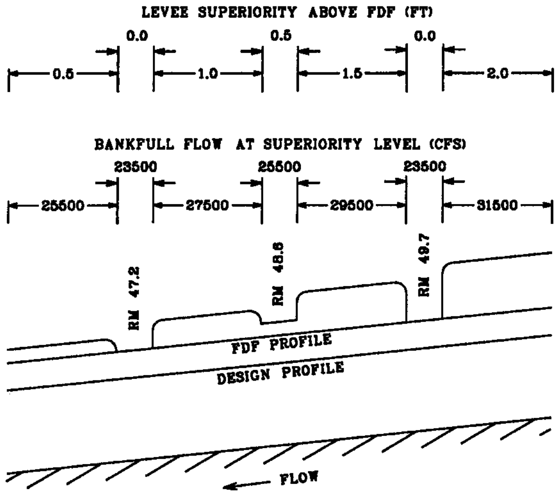

FIGURE 1. FREEBOARD SCHEMATIC - NOT TO SCALE

Freeboard Design Performance

The performance of the freeboard design was assessed by computing flow profiles for events greater than the design event. The proposed reach superiority and overtopping sections results in a peak inflow capacity to the reach of 31,500 cfs. The peak inflow rate was computed at the top of levee and assumed no significant failure of project structures. Based on the superiority of each reach, an analysis of HEC-2 computed water surface profiles at several flow rates determined the following overtopping scenarios:

1. Discharge above the FDF of 23,500 cfs but not exceeding 31,500 cfs: As the inflow hydrograph rises above the FDF discharge, the upstream most overtopping point would first spill. As the river discharge increases, the downstream most, then middle overtopping points would spill in sequence. Overflow is projected at the three overtopping

locations only. At the upstream peak in-river capacity inflow of 31,500 cfs, the computed water surface elevation exceeded the grade elevation of the earth overtopping sections at RM 47.2 and 48.6 by approximately 0.5 to 0.8 feet and the floodwall section at RM 49.2 by 1.5 to 1.7 feet. Peak discharge computed at all overtopping sections was 2000 cfs.

2. Discharge exceeding 31,500 cfs: Prior to this in-river discharge, overtopping of the levees/floodwalls would have been initiated downstream of RM 49.7. Some levee breaching may occur prior to attaining this discharge in the vicinity of the RM 47.2 and/or RM 48.6 initial overtopping points as these locations are earth embankment levees. Although overtopping at the RM 49.7 location would have occurred, this is a floodwall location which is expected to be capable of withstanding overtopping without failure. Levee breaching at the two most downstream overtopping points may cause some localized drawdown of the river water surface profile, possibly slightly increasing the in-river discharge capacities in this location. As flows exceed 31,500 cfs, continued breaching of the levee at the initial overtopping points may occur as well as other locations throughout the entire reach. As inflows approach the peak SPF flow, flooding in the adjacent landside areas would peak through the overtopping points initiated at the lower flows.

Summary

A freeboard design methodology was presented based on evolving design guidelines which proposes the use of levee superiority with initial overtopping at least hazardous locations. Application of the design guidelines was illustrated on the Truckee Meadows project. The freeboard design utilized multiple overtopping points and varying levels of levee superiority. Evaluation of the freeboard design was examined for flow events exceeding the project design event.

This paper represents the views of the authors and not necessarily those of the U.S. Army Corps of Engineers.

References

EM 1110-2-1601 (1970), "Hydraulic Design of Flood Control Channels", Department of the Army - U.S. Army Corps of Engineers, Washington D.C.

ETL 1110-2-299 (1986), "Overtopping of Flood Control Levees and Floodwalls", Department of the Army - U.S. Army Corps of Engineers, Washington D.C.

Huffman, R. G. (1990). "Freeboard on Flood Damage Reduction Structures - Issues and Problems", presented at the U.S. Army Corps of Engineers Hydraulics and Hydrology Conference, May 1990, Portland, Oregon.

Conversion Factors: 1 km = 0.621 mile, 1 m = 3.28 ft, 1 m^3/sec = 35.33 ft^3/sec.